Achieving Multi-User Capabilities through an Indoor Positioning System based on BLE Beacons

Mario Quinde*†, José Giménez-Manuel*, Chimezie Leonard Oguego*, Juan Carlos Augusto*

*Research Group on Development of Intelligent Environments,
Department of Computer Science
Middlesex University
London, UK
mq093@live.mdx.ac.uk, j.gimenezmanuel@mdx.ac.uk, co527@live.mdx.ac.uk, j.augusto@mdx.ac.uk
†*Departamento de Ingeniería Industrial y de Sistemas*
Universidad de Piura
Piura, Perú
mario.quinde@udep.edu.pe

***Abstract*—The multiple user challenge is one of the issues that need to be addressed in order to facilitate the adoption of intelligent environments in everyday activities. The development of multi-user capabilities in smart homes is closely related to the creation of effective indoor positioning systems. This research work reports on the development and evaluation of an indoor positioning system that allows multi-user management in a smart home environment. The design of the BLE based system is presented, as well as its implementation and evaluation in the Smart Spaces Lab at Middlesex University. The validation of the system is shown as a case study in which it is used to develop multi-user capabilities in two context-aware systems of the laboratory. Video demonstrations are provided to illustrate the multi-user capabilities that were developed in the validation.**

***Index Terms*—indoor positioning systems, multiple users, BLE beacons, context-aware reasoning, intelligent environments**

I. Introduction

The evolution of information and communication technology has allowed the development of solutions that can be categorised under the scope of Intelligent Environments (IE). These solutions are systems that integrate environments enriched with sensing devices (smart environments) with intelligent software supporting people in their daily activities (ambient intelligence) in order to provide pervasive/ubiquitous services [1]. One of the current challenges in the development of IE is the creation of solutions capable of differentiating among several users that may be interacting with the system. Addressing this multiple user (multi-user) issue is important because it will allow to achieve the delivery of customised services depending on the profile of each user.

This research work contributes to addressing the multi-user challenge by developing a system based on Bluetooth Low Energy (BLE) beacons that can be used to differentiate among several users in a smart home environment. The system uses BLE beacons to identify the indoor location of a user by determining what the closest beacon to their smartphone is. This location, which is presented as the room where the user is located, is then stored and made accessible to the learning and reasoning systems defining the behaviour of the smart home. Thus, these systems can adapt the behaviour of the smart home considering the profile of the user that was identified.

The system also contributes to addressing the indoor localisation issue that is also studied under the scope of the IE research area. Global navigation satellite systems (like GPS) are already established in the market and delivering benefits in outdoors environments. Nevertheless, there is the necessity of developing intelligent indoor positioning systems given the fact that the accuracy of the global navigation satellite systems drastically decreases in indoor scenarios due to several factors [2], [3]. This research work suggests locating the room in which the user is, in what can be considered as a simple and non-intrusive way.

The indoor localisation system is implemented in a smart home environment and evaluated through two experiments. The research work also presents the validation in the form of a case study in which two context-aware reasoning systems are enhanced for being able to cope with multi-user occupancy using the indoor localisation system[1]. The first one is an Ambient Assisted Living (AAL) system that provides support to people living with dementia (PwD). One of its features is detecting when the PwD is wandering. It then performs some actions (like issuing alerts) when this is detected. The second system uses prioritised users' preferences to solve conflicting situations that occur within an intelligent environment. In this case, a smart home. The conflicts occur due to clashes in the users' preferences. These systems were implemented in the Smart Spaces Lab in Middlesex University, London[2].

[1]The case study reported in the validation of this research work was part of the demonstration that was performed in the Real AI 2019 competition organised by the British Computer Society. This demonstration was the winner one of the competition (www.bcs-sgai.org/micomp/intro.php).

[2]http://ie.cs.mdx.ac.uk/smart-spaces-lab/

The rest of the paper is divided into five sections. Section II discusses the previous research work that is related to the multi-user and indoor localisation issues. Section III presents the main contribution of this research work, which is the indoor localisation system allowing multi-user capabilities in a smart home and its evaluation. Section IV describes the case study in which the indoor localisation system was used to upgrade two context-aware systems in the Smart Spaces Lab. Finally, sections V and VI show the discussion and conclusions of the research work reported in this paper.

II. Related work

The multiple user issue has been acknowledged as a key challenge to address in the IE research area. Augusto et al. [1] explain the necessity of identifying each one of the users interacting with an IE at all times, and present the complexity of the multi-user issue by showing that these users may coexist, interact, cooperate and conflict. The delivery of specialised services that are better aligned to a specific user profile is considered as one of the main benefits that systems implementing multiple user capabilities can provide [4].

Several approaches have been tried to address the multi-user challenge in smarthomes. From a conflict resolution perspective, [5], [6] are examples of implementing multi-user capabilities in a smart home environment. Both research works use the profiles of the users in the form of roles and preferences to achieve conflict resolution through a context-aware virtual assistant. The identification of multiple users in a smart home has been studied using different technologies that imply the use of also different techniques. A survey showing the existing approaches and practices coping with multioccupant smart homes for activity recognition can be found in [7].

Indoor positioning systems (IPS) can be considered as a research area that is closely related to allowing multi-user capabilities in smart home environments. Although IPS are not able to fully identify a user at all times, the location of the user is an important element to build up their context, which can then be used in the identification process. Given the fact that this research work studies technology that needs infrastructure deployment, some previous research works belonging to this category are presented as related work. Reference [8] presents an example of using RFID to identify humans passing through specific places. The use of WiFi fingerprint to provide location services has been studied in [9]–[11]. An example of using image processing to allow indoor localisation is provided in [12]. Finally, the research works presented in [13]–[17] study the use of Bluetooth technology to develop IPS.

The technology that is used to create IPS is still not well-established in the market yet, despite the several advances that are being done in the subject. This is because there still are shortcomings that must be overcome for each type of technology. For instance, the use of WiFi fingerprint involves a recalibration process that should be done every certain time depending on several factors. More information about this and an approach to overcome it can be found in [18]. Video processing is an example in which the privacy issues that are associated with the research area are not addressed by the technology. Other proposals (e.g. RFID, Bluetooh) require to spend more resources in the installation of the technology.

The research work presented in this paper has been guided by the works reported in [2], [19], in which Bluetooth Low Energy (BLE) beacons are suggested as a suitable technology to achieve indoor localisation and multi-user management in smart environments. These research works link the benefits of this technology to the low price, small size and low battery consumption of the BLE beacons, which are also considered as appropriate to overcome the privacy concerns in the research area. The shortcomings of using BLE beacons are related to the necessity of installing ad-hoc and sometimes complex infrastructure in the environment where the BLE beacons will be deployed. The benefits and shortcomings of this technology are explained and discussed throughout the paper.

III. An indoor localisation system using BLE technology to achieve multi-user capabilities

The main element of the indoor localisation system is an Android mobile application that scans the BLE beacons installed in the smart home environment and selects the one with the highest signal strength. All the beacons are associated with a specific room of the smart home, so the selected beacon is used as the indicator to determine the room where the user is at a specific moment. Thus, the system provides distance estimation based on signal strength. For this, the BLE beacons must be installed at strategic places in the smart home. Moreover, there is the assumption that users must have their smartphone (smartwatch, smartband or any device where the mobile application is running) with them while they are performing their activities. The mobile application must be configured to assign an identifier to each user.

The highlights of the indoor localisation system can be summarised in two main points. The first one is the algorithm that is used to scan the BLE beacons and send the information to the server in which the trace of each user is stored. The second is the distribution of the beacons in the smart home. The logic behind the system is explained below. The implementation of the system in the Smart Spaces Lab is then shown in section III-A.

The rooms where the activities will be performed is represented by $R = \{R_1...R_r\}$ with $|R| = r \in \mathbb{N}^+$. The set representing the BLE beacons that are installed in the smart home is $B = \{B_1...B_b\}$ with $|B| = b \in \mathbb{N}^+$. The association that defines the distribution of the beacons by linking each of them to the rooms is $D = \{\langle R_i, B_j\rangle, ...\}$, $1 \le i \le r$, $1 \le j \le b$. The users being monitored are represented by $U = \{U_1...U_u\}$, with $|U| = u \in \mathbb{N}^+$. The data the system stores to keep track of the localisation of the users is a set of elements $e = \langle ts, U_x, B_y\rangle$, $1 \le x \le u$, $1 \le y \le b$. This element e represents the closest beacon (B_y) to user U_x at time stamp ts. With this, it is possible to know the room where user U_x is at ts by searching in D for the room that is linked to B_y.

The algorithm the mobile application uses to determine and store e is shown in algorithm 1. U_x is a code that has been previously assigned to the user in the mobile application. This means that each smartphone must have a different user assigned in the mobile application. The previous closest beacon that was stored in the database is represented by $previousB_y$. The time stamp of the previous e that was stored is represented by $previousTS$. The values of $previousB_y$ and $previousTS$ change every time the system stores a new e. The first time the system is started, $previousB_y$ is set to "" and $previousTS$ is set to the time stamp when the system starts. The function *moving()* is implemented using the smartphone accelerometer and represents whether the user is moving (*true*) or not (*false*). The *while* loop means that the algorithm is running in the background all the time. Every time the loop is repeated, the MAC address of closest beacon to the smartphone is stored in B_y. The system then builds and stores the new e only if the user is *moving*, and either the new closest beacon is different to the previous one that was stored or it has passed more than 60 s since the previous e was stored (whichever happens first).

Algorithm 1 Determining and storing $e = \langle ts, U_x, B_y \rangle$

Input: U_x

```
previousB_y ← ""
previousTS ← getSystemTimeStamp()
while running do
    B_y ← getClosestBeacon()
    TS ← getSystemTimeStamp()
    if (previousB_y ≠ B_y or
    (TS − previousTS) ≥ 60s) and
    moving() then
        storeInformation(TS, U_x, B_y)
        previousTS ← TS
        previousB_y ← B_y
    end if
end while
```

The use of the smartphone accelerometer to detect movement is one of the novelties that have been included in the system. Not storing information when movement is not detected allows to change the current location only when there is the certainty that the user has moved. By doing this, if the user is still, e.g. working on the desk of their office, and the mobile application wrongly detects a beacon that is in another room as the closest one, then this mistake will not be stored because the system assumes that the user did not move.

A. Implementation of the indoor localisation system

The system was implemented in the Smart Spaces Lab, which is a smart home environment that is located in Middlesex University, London (UK). The implementation was done following the Smart Environment Architecture (SEArch) that is summarised in Fig. 1. The indoor localisation system is mainly related to the *Sensors HCI* component of SEArch, which gets information from the *Human(s)* to the database. In this specific case, the mobile application gets the closest beacon (sensor) to each user (human) at a specific time, and stores these data in the database server. The data can then be processed to build up context that is used by the *Learning* and *Reasoning* systems of the smart environment. A deeper explanation of SEArch can be found in [4].

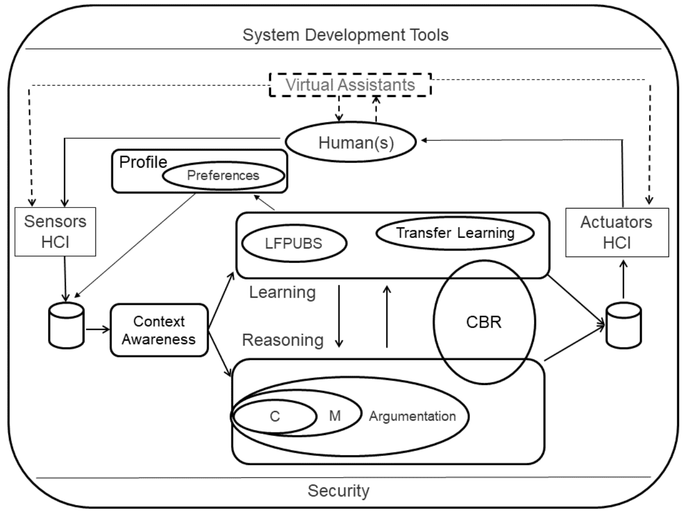

Fig. 1. The Smart Environment Architecture [4]

The beacons were installed on the ceiling of some specific rooms of the Smart Spaces Lab. The rooms that were used for the experiment are marked with a Bluetooth symbol in Fig. 4, which shows the rooms distribution of the laboratory. The Bluetooth symbol means that two beacons were installed in that room. The beacons were located at the center of each room with a distance of 1 meter between both beacons. The beacons that were used are the Short Range iBeacon[3] from Avvel International, which were configure to a broadcasting rate of 1s. An image of the beacons is shown in Fig. 2.

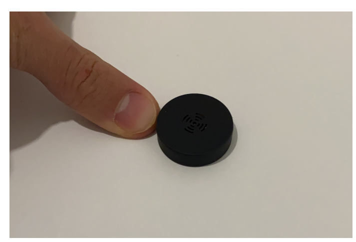

Fig. 2. Short Range iBeacon (Avvel International)

The mobile application implementing the logic shown in algorithm 1 stores the information in an independent database (in the server of the laboratory) that is accessible by any other system that is running in the laboratory. Figure 3 shows the only screen of the mobile application, where the user must enter their identifier (*User_ID*) before starting the application. Algorithm 1 is executed when the application is started. The other fields shown in the screen are automatically filled with the information of the latest closest beacon (B_y) that was stored. *Name* is the number of the beacon, which in this case is a number that helps to identify each beacon easier in a real

[3]For more information go to www.avvel.co.uk/shop/short-range-ibeacon-1

time experiment, *Address* is the MAC address of the beacon, and *RSSI* is the detected intensity of the beacon. These data change every time the mobile application stores a new B_y. The information about the users (U), rooms (R), beacons (B) and distribution (D) must be previously stored in the database.

Fig. 3. Main screen of the mobile application

B. Evaluation of the indoor localisation system

This section presents two experiments that were done to evaluate the system whose implementation is described in section III-A. The first experiment involved a participant that spent some time in three rooms of the laboratory doing random activities related to the room in which they were. The second experiment was similar to the first one but involved two participants doing activities in the same room. The participants had their smartphones, in which the mobile application described in section III-A was running, in their trousers pockets while doing the activities. Thus, the system kept track of the rooms in which the participants were.

The results obtained for the first experiment are shown in table I. The *time spent* column refers to the number of seconds the participant spent in each room. *Correct* refers to the number of seconds that the system correctly located the participant in the room where they were. The values for the *Correct* column were calculated after processing the data stored in the database, considering that the system does not send information about the closest beacon every second, but following the logic explained in algorithm 1.

TABLE I
EXPERIMENT 1: RESULTS SUMMARY

	Living room	**Kitchen**	**Bedroom**	**Overall**
Time spent (s)	241	317	332	890
Correct (s)	240	269	301	810
Accuracy	99.59%	84.86%	90.66%	91.01%

The results of the second experiment are shown in table II. The interpretation of this table is similar to the one used for table I, but considering that table II disaggregate the results according to each participant (*P1* and *P2*). It is important to highlight that participant 1 (P1) was noticeably less active than P2 when they were doing their activities.

TABLE II
EXPERIMENT 2: RESULTS SUMMARY

		Living room	**Kitchen**	**Bedroom**	**Overall**
Time spent (s)		361	316	382	1059
P1	Correct (s)	356	281	381	1018
	Accuracy	98.61%	88.92%	99.74%	96.13%
P2	Correct (s)	359	302	367	1028
	Accuracy	99.45%	95.57%	96.97%	97.07%

IV. IMPLEMENTING MULTI-USER CAPABILITIES USING THE INDOOR LOCALISATION SYSTEM

This section presents a case study showing how two context-aware systems of the Smart Spaces Lab were upgraded for being able to implement multi-user capabilities using the indoor localisation system reported in this research work. Both systems were modified to query the database in which the indoor location of the users is stored. Thus, the systems can personalise their behaviour depending on the profile of the user that is at a specific room. Videos demonstrating the upgraded capabilities are provided to illustrate the case study.

A. An AAL system supporting people living with dementia

The first system of the case study is an AAL system aiding PwD when they begin to have difficulties in their activities of daily living (ADLs). The cognitive decline PwD experience make them lose track of time and organisation, which causes a progressive loss of alignment in their ADLs and some common psychical behaviors such as wandering. The system supports PwD to avoid the distress and unhealthy lifestyle that they usually go through, by providing them with tools that allow a healthy alignment in their ADLs and alert their carers in some risky situations. The importance of this as well as of monitoring the occurrence of PwD ADLs is explained in [20].

One of the main elements of the AAL system is the activity recognition component that is used to detect when PwD ADLs are unusual. Some examples of unusual activities are: shifting mealtimes, sleeping during the day and staying awake during the night, elopement (leaving home at unusual times, e.g. 3 AM), and wandering around the house with no reason. The system allows users, who can be PwD or their carers, to configure the activities they consider as normal. This customisation is then used by the activity recognition component to detect deviations in the PwD ADLs.

This case study focuses on upgrading the AAL system capability that detects wandering behaviour of a PwD. This feature of the system is able to detect wandering behaviour based on previously customised rules. For this, the system uses a boolean variable $pattern$ that has the value of 0 when

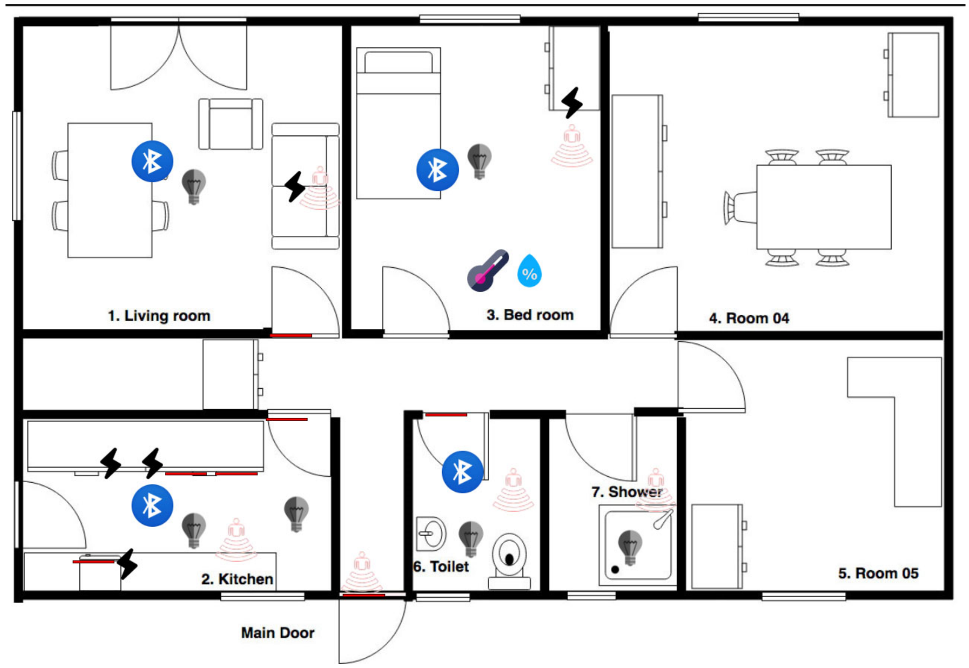

Fig. 4. Smart Spaces Lab: rooms distribution

the system starts and gets the value of 1 when the user goes from one room to another. The variable $pattern$ goes back to 0 when the user does not visit another room after w seconds, but $pattern$ stays as 1 if the system detects that the user visits another room before w seconds. The wandering behaviour is identified when it is detected that $pattern$ has had the value of 1 for more than z seconds uninterruptedly. The values of w and z can be customised through a web application interface.

The indoor localisation system aids to address the multi-user issue of using only Passive Infrared Sensors (PIRs) at each room of the smart home to detect the wandering behaviour previously described. Using only PIR does not allow to differentiate between a PwD and a relative/caregiver living in the same house. This issue can be explained using the following scenario. If the carer visits several rooms while the PwD is sleeping in his bedroom, the AAL system may detect wandering behaviour because the PIRs may recognise that there is activity at different rooms for more than z seconds uninterruptedly. The upgrade of the AAL system is based on using the outcomes of the indoor localisation system to confirm whether a person that is changing between rooms is the one with dementia or not. Thus, the AAL is upgraded for being able to detect wandering behaviour only when the one who is visiting several rooms is the PwD.

The activity recognition component of the AAL system is part of the *Reasoning* element of SEArch (Fig. 1). It has been implemented through Mreasoner, which is rule-based system that can reason with time events. The enhanced rules that were used to allow the AAL system to implement multi-user capabilities in its activity recognition component are in [21]. More information about MReasoner can be found in [22].

The video illustrating the multi-user capability of the AAL system is in [23]. The video shows two users in the Smart Spaces Lab that are represented by two icons (red and yellow) in a dynamic version of the map shown in Fig. 4. The first part of the video is about the first user (red) simulating the behaviour of a PwD that visits several rooms aimlessly. When this happens, MReasoner detects wondering behaviour and issues an alert through a mobile application to the carer of the PwD. The second part of the video shows the second user (yellow) visiting several rooms collecting some things. The video shows that MReasoner recognises that this user is not the PwD and it does not detect wandering behaviour. A screenshot of the video is shown in Fig. 5.

B. Using argumentation to manage users' preferences

The second system of the case study (known as Hybrid System) is an extended reasoning system that was enhanced using argumentation technique to identify and solve conflicts in AAL [24]. The Hybrid System uses preferences ranked by the user to solve conflicts. The preferences are in the form of a user profile that is created by the user at the beginning. The user creates their profile by selecting and ranking the preferences that apply to them. The ranked preferences are what the Hybrid System uses to solve the conflicts.

The Hybrid System has been upgraded for being able to identify the user that is at a specific room and use the ranking of preferences of that user to solve conflicts related to the room in which the user is. For this, the system uses the outcomes of the indoor localisation system to identify the location of the user. It then adapts the behaviour of the smart home considering the ranking of preferences of the identified user. For this, there is the assumption that the users have previously

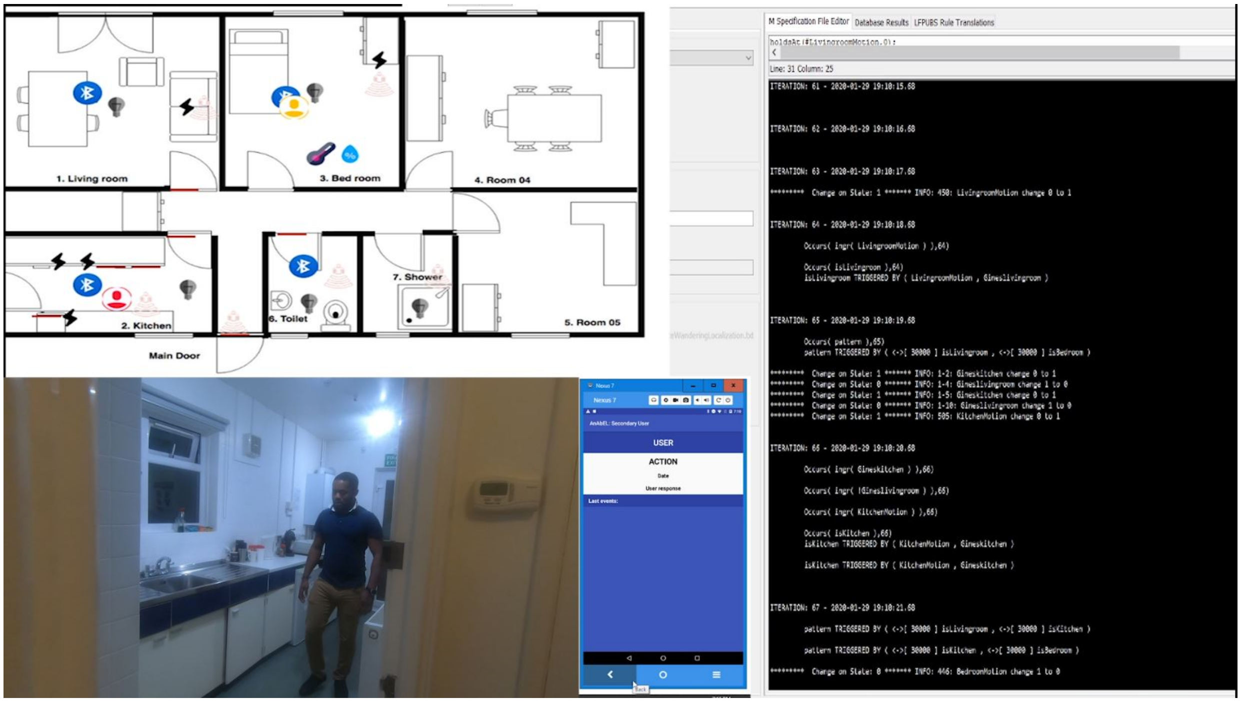

Fig. 5. Screenshot of the video demonstrating the multi-user capability of the AAL system

defined their ranking of preferences, which can be done using the web application that is reported in [25].

The video illustrating the new capability of the Hybrid System can be found in [23]. The video shows the Hybrid System, a dynamic map (Fig. 4) showing the location of two users (Jose and Bob), and the living room. The first part of the video shows Jose going from the bedroom to the living room and taking sit on the couch. The system detects that there is someone sitting on the couch because there is a pad sensor under the cushion of the couch. It then uses the preferences of Jose to define the behaviour of the smart environment. Thus, it only leaves the small lamp on because Jose previously assigned a higher rank to “economy” in their preferences profile. The second part of the video shows Bob going from the bedroom to the living room and taking sit on the couch. The system detects that, in this case, Bob is the one sitting on the couch. The system then turns on the lights and the television in the living room because Bob has a higher ranking on “entertainment” than “economy” in their preferences profile. Figure 6 shows a screenshot of the video.

V. Discussion

One of the motivations that led to develop the implemented system was facilitating the installation of indoor localisation systems in smart home environments. This research work does not claim that the design of this system is the best, but it is studied as an alternative to simplify the adoption of this type of systems. The system requires users to have their smartphones with them when they perform their activities, but not any other accessory that can be considered as an extra object to wear (like the BLE tags used in [17]). The system does not need to be calibrated/re-calibrated with machine learning algorithms, which is a challenging process in some IPS, like those using WiFi fingerprints (see [3] as an example). However, it is critical to install the BLE beacons at strategic places of the building. This ad-hoc installation of the beacons is expected to be a bigger challenge in buildings with rooms that are heterogeneous in terms of extension.

The algorithm that was implemented in the mobile application does not send and store information in the database every certain amount of time. It only stores information when a change in the location of the user has been detected. This reduces the number of records in the database where the traces of the users are stored. However, it requires to process the stored data considering intervals of time in order to determine the location of a user at a specific time. This is considered as a challenge of using the algorithm.

The evaluation of the system showed positive results for the two experiments that were done. The results show that the system was more accurate in the living room and less accurate in the kitchen, for both experiments. Another important point to highlight is the fact that the overall accuracy of the system was higher for the second experiment, in which two users were at the same room. Although the transitions between rooms were not evaluated, the system is expected to be less reliable when someone is moving from one room to another because of the beacons distribution that was implemented. This also applies to locations that are equidistant to the centre of two different rooms and when there are objects significantly disrupting signals of the beacons. A more exhaustive evaluation

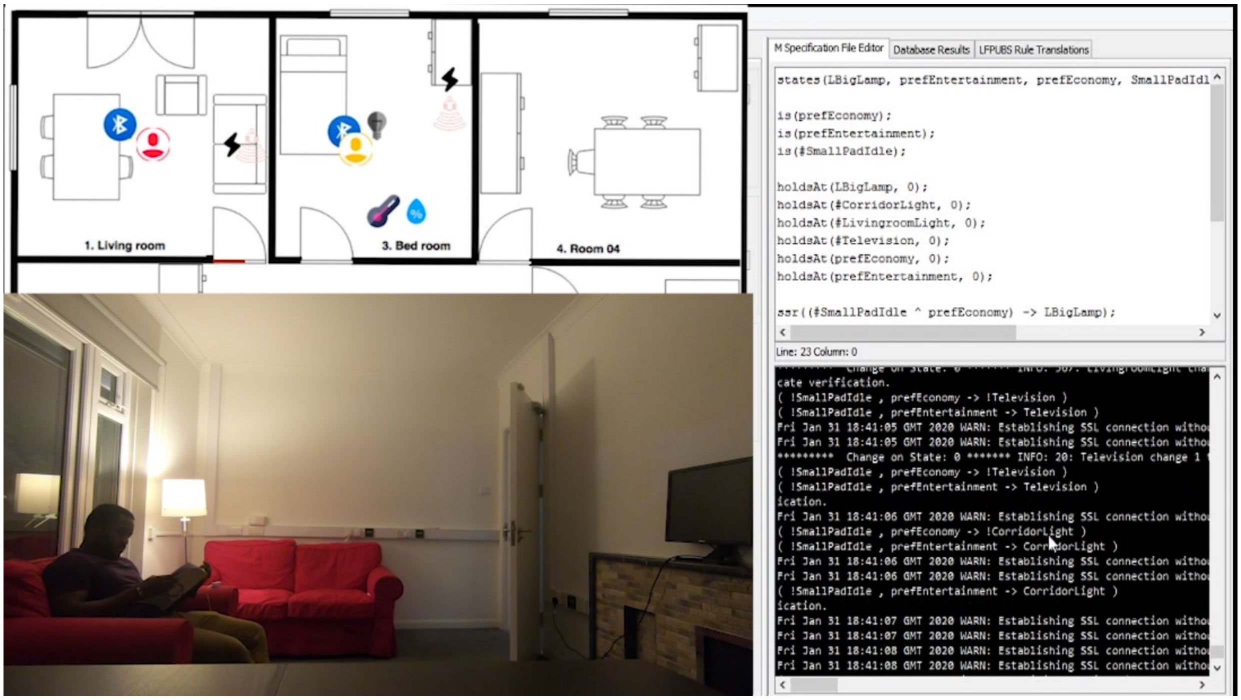

Fig. 6. Screenshot of the video demonstrating the multi-user capability of the Hybrid System

of the system is suggested as future work. It is also important to clarify that the indoor localisation system only identifies when the user is in a specific room. It cannot identify when the user is at the corridors of the smart home.

The indoor localisation system was used to enhance two context-aware systems that were implemented in the Smart Spaces Lab. The systems were satisfactory enhanced for being able to deal with multi-user occupancy. The AAL system was able to detect wandering behaviour only when the person visiting different rooms was the PwD. The Hybrid System was improved for being able to use the preferences profile of the user that was in a specific room, in order to solve conflicts that were occurring. A shortcoming of the indoor localisation system was observed when it was used to enhance the Hybrid System. If two or more users are in the same room, the Hybrid System uses the preferences profile of the user that was latest detected in the room by the indoor localisation system.

VI. Conclusions

This research work reports on the development of an indoor localisation system that allows the implementation of multi-user capabilities in the systems defining the behaviour of a smart home environment. The system identifies and stores the location of the users in the form of the room where they are at a specific time. This information can be accessed by other systems in order to include the users' indoor location in their context-aware reasoning logic. The design of the system facilitates its installation. The mobile application that is part of the system uses the accelerometer of the smartphone to store information only when it is needed. The indoor localisation system was evaluated through two experiments showing positive results. Two context-aware systems of the Smart Spaces Lab were enhanced for being able to cope with multi-occupancy, using the outcomes of the indoor localisation system. This validation shows that the indoor positioning system permits an easy integration with other systems of the smart home. The benefits, shortcomings and points for improvement of the system were presented as part of the discussion of the research work.

References

[1] J. C. Augusto, V. Callaghan, D. Cook, A. Kameas, and I. Satoh, "Intelligent environments: a manifesto," *Human-centric Computing and Information Sciences*, vol. 3, no. 1, p. 12, 2013.

[2] F. Palumbo, P. Barsocchi, S. Chessa, and J. C. Augusto, "A stigmergic approach to indoor localization using bluetooth low energy beacons," in *2015 12th IEEE International Conference on Advanced Video and Signal Based Surveillance (AVSS)*, Aug 2015, pp. 1–6.

[3] J. Torres-Sospedra, R. Montoliu, S. Trilles, O. Belmonte, and J. Huerta, "Comprehensive analysis of distance and similarity measures for wi-fi fingerprinting indoor positioning systems," *Expert Systems with Applications*, vol. 42, no. 23, pp. 9263 – 9278, 2015.

[4] J. Augusto, J. Gimenez-Manuel, M. Quinde, C. Oguego, M. Ali, and C. James-Reynolds, "A smart environments architecture (search)," *Applied Artificial Intelligence*, vol. 34, no. 2, pp. 155–186, 2020.

[5] K. Nurgaliyev, D. D. Mauro, N. Khan, and J. C. Augusto, "Improved multi-user interaction in a smart environment through a preference-based conflict resolution virtual assistant," in *2017 International Conference on Intelligent Environments (IE)*, 2017, pp. 100–107.

[6] B. Ospan, N. Khan, J. Augusto, M. Quinde, and K. Nurgaliyev, "Context aware virtual assistant with case-based conflict resolution in multi-user smart home environment," in *2018 International Conference on Computing and Network Communications (CoCoNet)*, 2018, pp. 36–44.

[7] A. Benmansour, A. Bouchachia, and M. Feham, "Multioccupant activity recognition in pervasive smart home environments," *ACM Comput. Surv.*, vol. 48, no. 3, 2015.

[8] M. Zhi and M. Mahinderjit Singh, "Rfid-enabled smart attendance management system," in *Future Information Technology - II*, J. J. J. H. Park, Y. Pan, C. Kim, and Y. Yang, Eds. Dordrecht: Springer Netherlands, 2015, pp. 213–231.

[9] O. Belmonte-Fernandez, A. Puertas-Cabedo, J. Torres-Sospedra, R. Montoliu-Colas, and S. Trilles-Oliver, "An indoor positioning system based on wearables for ambient-assisted living," *Sensors*, vol. 17, no. 1, 2017.

[10] J. Torres-Sospedra, R. Montoliu, S. Trilles, O. Belmonte, and J. Huerta, "Comprehensive analysis of distance and similarity measures for wi-fi fingerprinting indoor positioning systems," *Expert Systems with Applications*, vol. 42, no. 23, pp. 9263 – 9278, 2015.

[11] O. Belmonte-Fernandez, A. Gasco-Compte, E. Sansano-Sansano, M. Quinde, J. Gimenez-Manuel, and A. J.C., "Evaluation of crowdsourcing wi-fi radio map creation in a real scenario for aal applications," in *Proceedings of 15th International Conference on Intelligent Environments*. IEEE, 2019.

[12] R. Aboul Naga, R. Elias, and A. El Nahas, "Indoor localization using cluster analysis," in *Artificial Intelligence and Soft Computing*, L. Rutkowski, R. Scherer, M. Korytkowski, W. Pedrycz, R. Tadeusiewicz, and J. M. Zurada, Eds. Cham: Springer International Publishing, 2019, pp. 3–13.

[13] P. Baronti, P. Barsocchi, S. Chessa, F. Mavilia, and F. Palumbo, "Indoor bluetooth low energy dataset for localization, tracking, occupancy, and social interaction," *Sensors*, vol. 18, no. 12, 2018.

[14] P. Barsocchi, A. Crivello, M. Girolami, F. Mavilia, and F. Palumbo, "Occupancy detection by multi-power bluetooth low energy beaconing," in *2017 International Conference on Indoor Positioning and Indoor Navigation (IPIN)*, 2017, pp. 1–6.

[15] F. Brockmann, M. Handte, and P. J. Marron, "Cutiqueue: People counting in waiting lines using bluetooth low energy based passive presence detection," in *2018 14th International Conference on Intelligent Environments (IE)*, 2018, pp. 1–8.

[16] F. Kruger, M. Kasparick, T. Mundt, and T. Kirste, "Where are my colleagues and why? tracking multiple persons in indoor environments," in *2014 International Conference on Intelligent Environments*, June 2014, pp. 190–197.

[17] F. Mavilia, F. Palumbo, P. Barsocchi, S. Chessa, and M. Girolami, "Remote detection of indoor human proximity using bluetooth low energy beacons," in *Proceedings of 15th International Conference on Intelligent Environments*. IEEE, 2019.

[18] N. Fet, M. Handte, and P. J. Marron, "An approach for autonomous recalibration of fingerprinting-based indoor localization systems," in *2016 12th International Conference on Intelligent Environments (IE)*, 2016, pp. 24–31.

[19] D. Sora and J. C. Augusto, "Managing multi-user smart environments through ble based system," in *Ambient Intelligence and Smart Environments*, I. e. a. Chatzigiannakis, Ed., vol. 23. IOS Press, 2018, pp. 234–243.

[20] E. G. Kaufmann and S. A. Engel, "Dementia and well-being: A conceptual framework based on tom kitwood's model of needs," *Dementia*, vol. 15, no. 4, pp. 774–788, 2016.

[21] M. Quinde, J. Gimenez-Manuel, C. L. Oguego, and J. C. Augusto, "Ble indoor localisation: rules," Feb 2020. [Online]. Available: https://figshare.com/s/c72499cccc72b31fa2c1

[22] U. A. Ibarra, J. C. Augusto, and A. A. Goenaga, "Temporal reasoning for intuitive specification of context-awareness," in *2014 International Conference on Intelligent Environments*, 2014, pp. 234–241.

[23] M. Quinde, J. G. G. Manuel, C. L. Oguego, and J. C. Augusto, "Videos of the validation," 2020. [Online]. Available: https://doi.org/10.22023/mdx.12192576.v1

[24] C. Oguego, J. Augusto, A. Muñoz, and M. Springett, "Using argumentation to manage users' preferences," *Future Generation Computer Systems*, vol. 81, pp. 235 – 243, 2018.

[25] C. Oguego, J. Augusto, M. Springett, M. Quinde, and C. Reynolds, "Interface for managing users' preferences in ami systems," in *Proceedings of 15th International Conference on Intelligent Environments*. IEEE, 2019.